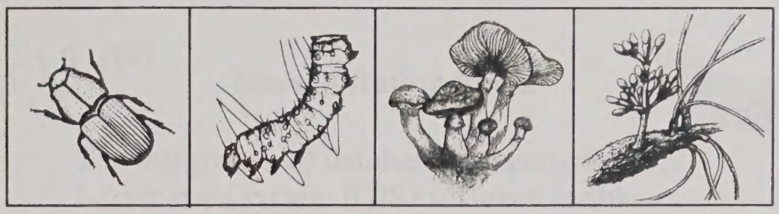
# Forest Health Protection



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## Revised R1 Forest Insect Hazard Rating System User Guide for use with Inventory Data Stored in FSVeg and/or Analyzed with the Forest Vegetation Simulator



Carol Randall[1], Brytten Steed[2], Renate Bush[3]
USDA Forest Service Region 1
[1]Entomologist, Forest Health Protection, Coeur d'Alene, ID
[2]Entomologist, Forest Health Protection, Missoula MT
[3]Regional Inventory Specialist, Renewable Resource Management, Missoula, MT



### Introduction

Forest insects and diseases are important disturbance factors in forest ecosystems. Insect and disease activity may dramatically alter the structure, composition, and age class distribution of forested stands and may interfere with a manager's ability to achieve established objectives. The purpose of the Forest Health Protection (FHP) division of State and Private Forestry is to assist land managers by identifying areas where insects and diseases may impact resource values. FHP personnel work with resource managers to devise responses that minimize the impacts of these agents of change.

As part of Region 1's Integrated Restoration and Protection Strategy, FHP entomologists devised bark beetle and defoliator hazard ratings for inventory data, such as from stand exams and Forest Inventory and Analysis (FIA) plots. These hazard ratings are available to assist land managers in three ways: they are keyword files that can be used with the Forest Vegetation Simulator (FVS) to determine current hazard and model hazards over time, with or without management or disturbances; all stand exam, FIA, and intensified grid inventory data which reside in FSVeg have these hazard ratings calculated during the post-load process and stored in FSVeg tables; and these ratings are available in the R1 Summary Database Analysis tools. This document discusses forest insect hazard ratings, how they are derived, and how they may be used to assist land managers with planning.

Since the original publication of this report, (Randall and Bush 2010) modifications were made to the mountain pine beetle in lodgepole pine hazard rating logic, and a combined host pine beetle hazard rating was developed.

### Hazard Ratings

Forest insects require three things to cause significant impact to resource values: susceptible hosts; insect populations; and favorable weather conditions. Hazard rating systems measure the susceptibility of forested areas to a particular insect by evaluating the

amount of susceptible host. High and moderate hazard forested areas are more likely to experience significant mortality if insect populations are present and the weather is favorable.



### Data Considerations

When using hazard ratings in a landscape level analysis, it is assumed that available data are a representative sample of landscape conditions. A spatially balanced inventory across the geographic area of interest can be used to derive estimates of hazard, however, small forested areas, or areas with unique characteristics, may not be represented or have insufficient data for analysis. Users should carefully evaluate available data for a particular analysis area to insure that a representative sample of current forest conditions exists. Hazard ratings calculated for a sampled area assumes that forest conditions in the sample area are homogeneous; if excessive variability in any of the parameters used to calculate hazard ratings occurs within the sampled area, the hazard rating may not accurately reflect the hazard. If that is the case, further stratification of the geographic area of interest into various dominance types, size classes, and densities may be needed.

Hazard ratings applied to stand exams will accurately reflect the stand at time of inventory. It is important to consider the age of the data when interpreting hazard. Many stand characteristics used to calculate hazard may have changed since the time of the exam. If data needs to be "modeled" to current condition, then FVS, and the associated hazard rating keyword files, should be used to model hazard to a contemporary inventory date. As always, it is prudent to ground check results.

### Hazard Rating Maps

The integration of database and geographic information system (GIS) software enables mapping of forested areas by their insect and/or disease hazard rating. Hazard maps enable managers to identify concentrations of high- and moderate-hazard areas across a landscape.

Large, contiguous forested areas of high insect hazard promote epidemic forest insect populations by providing large areas of quality food. When high-hazard areas are small and intermixed with low-hazard areas, forest insect populations are not as likely to grow and cause significant resource impacts. Low-hazard areas have host species for a particular insect, but the host is not of high enough quality and/or in large enough quantity to allow forest insect populations to build substantially. Forest insects may still cause significant mortality in the host components of low-hazard forested areas in a landscape, but losses will be lower than in a landscape where high-hazard forested areas occur across a number of contiguous acres.

### Appropriate Use of Hazard Maps

Spatial depictions of hazard are powerful tools for managers and planners at the broad- (Regional assessments), mid- (Forest assessment), and project-levels. Such maps help managers identify areas that have the highest probability of significant forest insect activity. Although hazard ratings do not predict when insects will damage resources, experience has shown that forest insects are most likely to occur in high hazard areas. Hazard ratings address the quality and quantity of food available, but do not address insect populations. Therefore, additional information is necessary to assess risk and predict loss.

Keep in mind the methods used to develop a hazard map. Many times the accuracy of the data is unknown. This does not mean that the maps are not useful. If developed correctly, using recent spatial and tabular data, they can provide information about areas that are most susceptible to forest insect outbreaks. Furthermore, due to stand/polygon heterogeneity, not every tree or plot within a high hazard polygon may be susceptible to the insect pest.

Understanding relationships of dominance type, size class, and canopy cover to various forest insect hazard ratings assists with developing forest insect hazard maps. Tools have been developed by the R1 vegetation analysis team to understand the relationships of vegetation classification attributes used in R1 (Barber *et al.* 2010) to the resulting hazard ratings. These relationships can then be applied to existing vegetation layers such as R1-VMap, FSVeg Spatial, or a hybrid of the two. Furthermore, other spatial information such as elevation, potential natural vegetation, etc. can be integrated when developing these coverages.

## Project Planning

A hazard map is the easiest way for managers to quickly identify areas with the highest likelihood of significant forest insect activity. More information is needed to plan projects. At the project level the assumption that stands are homogeneous may no longer be appropriate. Additional information from a variety of sources, including recent walk-throughs, aerial photographs, insect aerial detection surveys and model runs (Forest Insect and Disease Tally System (FINDIT) (Bentz 2000) should be gathered to help determine which areas are most critical for treatment. The manager should also consider the current level of insect activity in the area. Current insect activity is the magnitude of an insect population affecting a forested area as determined by the number of currently infested trees and their proximity to the stand being assessed.

Insect activity is a dynamic variable and may change quite suddenly due to factors such as adverse or favorable weather conditions, or immigration and emigration of insects. For this reason insect activity should be reviewed every year or two.

## Ways to Alter Hazard: Management Considerations

Hazard can be altered through silvicultural practices that break up large, homogeneous blocks of susceptible forest that can host major insect and disease populations. Specific silvicultural practices to reduce hazard vary with the insect involved. Appropriate practices can be developed for specific land areas by various resource specialists, including entomologists and forest pathologists from FHP.

By using FVS and associated keywords for hazard ratings, various silvicultural prescriptions can be evaluated. Immediate and long-term effects for various management scenarios can be compared for how they affect hazard over time.

## Conclusion

The use of landscape hazard rating maps for forest insects will assist managers in determining the potential for these disturbance agents to interfere with a manager's ability to reach established objectives. By identifying high hazard areas prior to insect outbreaks, managers have an opportunity to reduce hazard through

silvicultural prescriptions, including prescribed fire, or to determine if action is warranted. Tools which look at hazard, from landscape-level hazard maps to hazard of a stand, prior to significant insect activity, allow managers to be proactive in addressing insect dynamics by altering hazard conditions instead of reacting to insect activity.

## References


Barber, J., Berglund, D., Bush, R. 2010. The Region 1 existing vegetation classification system and its relationship to inventory data and the Region 1 existing vegetation map products. Vegetation, Classification, Inventory, and Analysis Report # 10-08 6.0. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 30 p.

Bentz, B. 2000. Forest Insect and Disease Tally System (FINDIT) user manual. Gen. Tech. Rep. RMRS-GTR-49. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 12 p.

Randall, C., Bush, R. 2010. R1 forest insect hazard rating system user guide for use with inventory data stored in FSVeg and/or Veg Simulator. FHP Report 10-05. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 26 p.

## Insect Hazard Rating Systems Available to Region 1

Carol Randall and Lee Pederson, R1 FHP Staff, formulated the following hazard rating systems based on research cited in this document. Researchers identified site and stand characteristics associated with areas which experienced high levels of activity by forest pests. Hazard ratings are calculated by looking at a combination of site and stand characteristics and assigning a relative index value in terms of susceptibility to the pest. By multiplying the index values, a composite index is calculated, and the composite index is assigned a hazard rating. In the subsequent rating system descriptions for the individual insects the following formula is used.

Calculated Value = Criteria A rating * Criteria B rating * Criteria C rating

Each hazard rating system was translated into a Forest Vegetation Simulator (FVS) event monitor keyword set which calculates hazard using the original criteria in the published hazard rating system then summarizes hazard into 1 of 4 possible classes:

- ☐ 0 = No Host Present in Survey or Summary Data
- ☐ L or 1 = Low Hazard
- ☐ M or 2 = Moderate Hazard
- ☐ H or 3 = High Hazard.

See the Appendix for the keyword sets. These summary ratings (0, L, M, H) are displayed in FSVeg for R1 data, available in the R1 Summary Database analysis tool, and may be output by FVS.

The hazard criteria for the following insects and host combinations are in this document:

- spruce beetle (*Dendroctonus rufipennis*);
- Douglas fir beetle (*Dendroctonus pseudotsugae*);
- mountain pine beetle (*Dendroctonus ponderosae*) and western pine beetle (*Dendroctonus brevicomis*) in ponderosa pine;
- mountain pine beetle (*Dendroctonus ponderosae*) in western white pine
- mountain pine beetle (*Dendroctonus ponderosae*) in lodgepole pine
- mountain pine beetle (*Dendroctonus ponderosae*) in whitebark pine/ limber pine;
- western spruce budworm (*Choristoneura occidentalis*) and Douglas-fir tussock moth (*Orygia pseudotsugae*) in Douglas fir and true firs
- combined host pine beetle (*Dendroctonus* and *Ips* species)

Please note QMD = quadratic mean diameter, BA = basal area, DBH = diameter breast height. All metrics are in English units.

## Spruce Beetle

Spruce beetle outbreaks cause extensive tree mortality and modify stand structure by reducing the average spruce tree diameter, height, and stand density. Residual trees are often slow-growing small and intermediate-sized trees which eventually become dominant. In the Rocky Mountain West, Engelmann spruce (PIEN, ES) is the species most often impacted.

### Stand Conditions Conducive To Infestations

Endemic spruce beetle populations usually live in wind-thrown trees. When populations increase to high levels in downed trees, beetles may attack susceptible, large-diameter standing trees. Most outbreaks originate in wind-thrown trees. Once beetle populations reach high levels, more relatively healthy trees are attacked.

In mature stands, larger diameter (≥ 18" DBH) trees usually are attacked first. If an infestation persists in a stand, smaller diameter trees may be attacked.

In the Rocky Mountain area, susceptibility of a stand to spruce beetle attack is based on the physiographic location, tree diameter, basal area, and percentage of Engelmann spruce in the canopy. Engelmann spruce stands are highly susceptible if they grow on well-drained sites in creek bottoms, have an average DBH of 16 inches or more, have a BA greater than 150 square feet per acre, and have more than 65 percent spruce in the canopy. Since stand physiographic location is not captured in inventory data, it was omitted in the hazard calculation but could be added when generating a hazard map.

**Hazard Criteria for Spruce Beetle**

| Criteria | Attribute | Low (.5) | Moderate (2) | High(3) |
|---|---|---|---|---|
| A | QMD for Engelmann spruce ≥10" DBH | <12" | 12" ≤ QMD < 16" | ≥16" |
| B | BA for all species | <100 $ft^2$/ac | 100 ≤ BA < 150 $ft^2$/ac | ≥150 $ft^2$/ac |
| C | % of total BA that is Engelmann spruce ≥10" DBH | <50% | 50% ≤ % BA < 65% | ≥65% |

**Directly Calculated Hazard Values Hazard Rating Multiplicative Index**

| Hazard | Calculated Values | Hazard Rating |
|---|---|---|
| Extremely Low | 0 | 0 |
| Low | <2 | 1, L |
| Moderate | 2-17 | 2, M |
| High | ≥18 | 3, H |

## Interpreting Hazard

High hazard stands are those in which large amounts of spruce mortality can be expected once a spruce beetle outbreak occurs. Moderate and low hazard stands may experience less beetle-caused mortality; but individual large, old spruce might still be killed. When high-hazard stands are intermixed with low-hazard stands, beetle populations may not be as active. Low-hazard stands may have spruce, but are either not of high enough quality or in large enough quantity to allow beetle populations to remain at high levels. Spruce beetle may still cause significant mortality in the spruce component of low-hazard stands in a landscape, but losses will be lower than in a landscape where high-hazard stands are clustered.

## References

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Randall, C., Tensmeyer, G. 1999. Douglas fir beetle hazard rating system using the Oracle database and the Forest Service IBM platform. Forest Health Protection Report 99-6. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 5 p.

Schmid, J.M., Frye, R.H. 1976. Stand ratings for spruce beetles. Res. Note RM-309. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 4 p.

Steele, R., Williams, R.E., Weatherby, J.C., Reinhardt, E.D., Hoffman, J.T., Their, R.W. 1996. Standard hazard rating for central Idaho forests. Gen. Tech. Rep. INT-GTR-332. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 18 p.

## Douglas-fir beetle

Douglas-fir beetles normally kill small groups of trees, but during outbreaks groups of up to 100 trees are not uncommon. Outbreaks in standing trees range in duration from 2 to 4 years. Those of longest duration coincide with periods of drought.

### Stand Conditions Conducive To Infestations

At low or endemic levels, the Douglas-fir beetle infests scattered trees, including windfalls and trees injured by fire scorch, defoliation, or root disease. Where such susceptible trees are abundant, once they have been infested and killed, beetle populations can build up rapidly and spread to adjacent green, standing trees. Damage is greatest in dense stands of mature Douglas-fir. Various fungi introduced by the beetles also contribute to mortality of infested trees.

The likelihood of a Douglas-fir beetle infestation developing within a stand is related to the proportion of susceptible Douglas-fir and overall stand density. Generally, Douglas-fir beetle attacks are most successful on Douglas-fir trees that are mature or over-mature, large in diameter, and in more densely stocked stands. A very high stand density may increase the susceptibility of younger and smaller diameter Douglas-fir trees. The higher the proportion of trees with susceptible characteristics, the higher the susceptibility of the stand to Douglas-fir beetle attack.

**Hazard Criteria for Douglas-fir Beetle**

| Criteria | Attribute | Low (.5) | Moderate (2) | High(3) |
|---|---|---|---|---|
| A | QMD for Douglas-fir ≥9" DBH | <10" | 10" ≤ QMD < 14" | ≥14" |
| B | BA for all species | <100 $ft^2$/acre | 100 ≤ BA < 250 $ft^2$/acre | ≥250 $ft^2$/acre |
| C | % of total BA that is Douglas-fir ≥9" DBH | <50% | | ≥50% |

**Directly Calculated Hazard Values and Hazard Rating Multiplicative Index**

| Hazard | Calculated Values | Hazard Rating |
|---|---|---|
| Extremely Low | 0 | 0 |
| Low | <2 | 1, L |
| Moderate | 2-17 | 2, M |
| High | ≥18 | 3, H |

### Interpreting Hazard

High-hazard stands are those in which large amounts of Douglas-fir mortality is expected once a Douglas-fir beetle outbreak occurs. Moderate- and low-hazard stands may experience less beetle-caused mortality, but individual large, old Douglas-fir trees might still be killed.

When high-hazard stands are intermixed with low-hazard stands, Douglas-fir beetle populations may not be as active. Low-hazard stands may have Douglas-fir, but either not of high enough quality or in large enough quantity to allow Douglas-fir beetle populations to remain at high levels. Douglas-fir beetle may still cause significant

mortality in the Douglas-fir components of low-hazard stands in a landscape, but losses will be lower than in a landscape where high-hazard stands are clustered.

### References

Forest Service. 1999. Douglas-fir beetle in the Intermountain West. Forest Health Protection Leaflet R1-04-78. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain and Northern Regions

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Weatherby, J.C., Their, R.W. 1992. A preliminary validation of a Douglas-fir beetle hazard rating system, Mountain Home Ranger District, Boise National Forest. Forest Pest Management Report R4-93-05. Boise, ID: U.S. Department of Agriculture, Forest Service, Intermountain Region.

## Mountain Pine Beetle /Western Pine Beetle in Ponderosa pine

Ponderosa pine (PIPO, PP) is susceptible to a number of tree killing bark beetles including the mountain pine beetle, the western pine beetle, and the pine engraver beetle (*Ips pini*). Mountain pine beetle and western pine beetle are most likely to impact mature stands of ponderosa pine.

### Stand Conditions Conducive To Infestations

Bark beetles respond to stressed ponderosa pine. Stands most susceptible to bark beetle attacks have a high composition of susceptible host, or dense stands of large diameter ponderosa pine. There are some subtle differences in ponderosa pine stands susceptible to mountain pine beetles and those susceptible to western pine beetle, but for the purpose of analysis, we have combined these two beetles in the hazard rating criteria.

**Hazard Criteria for Mountain Pine Beetle/Western Pine Beetle in Ponderosa Pine**

| Criteria | Attribute | Low (.5) | Moderate (2) | High(3) |
|---|---|---|---|---|
| A | QMD of ponderosa pine $\geq$5" DBH | <6" | 6" $\leq$ QMD < 10" | $\geq$10" |
| B | BA all species $ft^2$/acre | <80 $ft^2$/acre | 80 $\leq$ BA< 120 $ft^2$/acre | $\geq$120 $ft^2$/acre |
| C | % of total BA that is ponderosa pine $\geq$5" DBH | <40% | 40% $\leq$ % BA< 65% | $\geq$65% |

**Directly Calculated Hazard Values and Hazard Rating Multiplicative Index**

| Hazard | Calculated Values | Hazard Rating |
|---|---|---|
| Extremely Low | 0 | 0 |
| Low | <2 | 1, L |
| Moderate | 2-17 | 2, M |
| High | $\geq$18 | 3, H |

### Interpreting Hazard

Hazard is defined by two factors--the quality and the quantity of susceptible ponderosa pine. The quality of the PP component of a stand as a mountain pine beetle or western pine beetle food source is best characterized by stand density and phloem thickness. Since ponderosa pine phloem thickness is not generally measured in most inventories, DBH and other available stand characteristics are used as surrogates. The quantity of the food source refers to the species composition and density of the forest. A pure, well stocked PP stand will be more likely to support a large mountain pine beetle population than a mixed species and/or poorly stocked stand.

When high-hazard stands are surrounded by low-hazard stands, beetle populations may not be as significant. Low-hazard stands may have ponderosa pine, but are either not of high enough quality or in large enough quantity to allow beetle populations to remain at high levels. Beetles may still cause significant mortality in the ponderosa pine components of low-hazard stands in a landscape, but losses will be lower than in a landscape where high-hazard stands are clustered.

## References


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## Mountain Pine Beetle in Western White Pine

Until about 75 years ago western white pine (PIAL, WP) was the most abundant forest type in the Northern Rocky Mountain province. The causes of change include mountain pine beetle, fire suppression, and past harvesting. The primary agent of change, however, is white pine blister rust (*Cronartium ribicola*). The rust, a disease of white pines, did not occur in North America until accidentally introduced into Vancouver Island, British Columbia about 1910. By the 1940s, the disease was epidemic in Idaho. Today, a combination of blister rust, mountain pine beetle, and past harvesting has nearly eliminated mature western white pine stands. Remaining large western white pines now exist mostly as scattered individuals.

White pine blister rust continues to kill most white pine trees that regenerate naturally and white pine blister rust and bark beetles continue to kill remaining large trees. Maintaining stands of white pine that remain is a high priority.

### Stand Conditions Conducive To Infestations

Based on historical accounts of past mountain pine beetle outbreaks, we know that dense stands (greater than 140 $ft^2$/acre BA) with a large component (> 60% stand BA) of large diameter (>8" DBH) white pine trees sustain the greatest losses to the mountain pine beetle.

**Hazard Criteria for Mountain Pine Beetle in Western White Pine**

| Criteria | Attribute | Low (.5) | Moderate (2) | High (3) |
|---|---|---|---|---|
| A | QMD white pine $\geq$5" DBH | <8" | 8" $\leq$ QMD < 12" | $\geq$12" |
| B | BA all species ($ft^2$/acre) | <80 $ft^2$/acre | 80 $\leq$ BA < 120 $ft^2$/acre | $\geq$120 $ft^2$/acre |
| C | % of total BA that is white pine $\geq$5" DBH | <25% | 25% $\leq$ % BA < 50% | $\geq$50% |

**Directly Calculated Hazard Values and Hazard Rating Multiplicative Index**

| Hazard | Calculated Values | Hazard Rating |
|---|---|---|
| Extremely Low | 0 | 0 |
| Low | <2 | 1, L |
| Moderate | 2-17 | 2, M |
| High | $\geq$18 | 3, H |

### Interpreting Hazard

High hazard is defined by two factors--the quality and the quantity of susceptible western white pine. The quality of the WP component of a stand as a mountain pine beetle food source is best characterized by stand density and phloem thickness. Since WP phloem thickness is not generally measured in inventories, DBH and other available stand characteristics are used as surrogates. The quantity of the food source refers to the species composition and density of the forest. A pure, well stocked WP stand will be more likely to support a large mountain pine beetle population than a mixed species and/or poorly stocked stand.

When high-hazard stands are intermixed with low-hazard stands, beetle populations may not be as significant. Low-hazard stands may have WP, but are either not of high enough quality or in large enough quantity to allow beetle populations to remain at high levels. Mountain pine beetle may still cause significant mortality in the WP components of low-hazard stands in a landscape, but losses will be lower than in a landscape where high-hazard stands are clustered.

**Reference**

Hagle, S., Johnson, T., Stipe, L., Schwandt, J., Byler, J., Kegley, S., Bell Randall, C., Taylor, J., Lockman, B., Sturdevant N. 2000. Successional functions of pathogens and insects; ecoregion sections M332a and M333d in northern Idaho and western Montana. Volume 1: Methods. Forest Health Protection Report 00-10. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 39-42 p.

## Mountain Pine Beetle in Lodgepole Pine

Mountain pine beetle attacks and kills lodgepole pine (PICO, LP). Epidemics frequently develop in lodgepole pine stands that contain well-distributed, large- diameter trees. When outbreaks are extensive, millions of trees may be killed each year. During epidemics, widespread tree mortality can alter the forest ecosystem. Often, beetles have almost completely depleted pine forests and, in some cases, have converted forests to other species, such as subalpine fir. Sometimes, forested areas are converted to grass and shrubs. The profusion of beetle-killed trees can change wildlife species composition and distribution by altering hiding and thermal cover, affecting forage and prey populations, and by impeding movement. Tree mortality may increase the water yield for several years following an infestation. Moreover, the dead trees left after epidemics are a source of fuel that will, in time, burn if not removed.

**Stand Conditions Conducive To Infestations**

Susceptible lodgepole pine stands are dense ($\geq$ 100 ft$^2$/acre BA) and have a large component ($\geq$50% BA) of large diameter ($\geq$8" DBH) lodgepole pine. Outbreaks may be limited once stand basal area becomes too large or if stands occur at high elevations.

In the original hazard rating system stand elevation and trees per acre were also incorporated into hazard rating calculation. After careful analysis of resulting hazard ratings we determined that the model for MPB in LP provided more consistent and appropriate results if the criteria for trees per acre 3" DBH or larger was dropped. Elevation was also eliminated as a warming climate may alter elevation threshold values.

**Hazard Criteria for Mountain Pine Beetle in Lodgepole Pine**

| Criteria | Attribute | Low (.5) | Moderate (2) | High(3) |
|---|---|---|---|---|
| A | QMD lodgepole pine $\geq$5" DBH | <7" | 7" $\leq$ QMD < 8" | $\geq$8" |
| B | BA all species (ft$^2$/acre) | <80 or $\geq$250 ft$^2$/acre | 80 $\leq$ BA < 120 ft$^2$/acre | 120 $\leq$ BA < 250 ft$^2$/acre |
| C | % of total BA that is lodgepole pine $\geq$5" DBH | <25% | 25% $\leq$ % BA < 50% | $\geq$50% |

**Directly Calculated Hazard Values and Hazard Rating Multiplicative Index**

| Hazard | Calculated Values | Hazard Rating |
|---|---|---|
| Extremely Low | 0 | 0 |
| Low | <2 | 1, L |
| Moderate | 2-17 | 2, M |
| High | $\geq$18 | 3, H |

### Interpreting Hazard

Hazard is defined by two factors--the quality and the quantity of susceptible lodgepole pine. The quality of the lodgepole component of a stand as a mountain pine beetle food source is best characterized by stand density and phloem thickness. Since lodgepole pine phloem thickness is not generally measured in inventories, DBH and other available stand characteristics are used as surrogates. The quantity of the food source refers to the species composition and density of the forest. A pure, well stocked lodgepole stand will be more likely to support a large mountain pine beetle population than a mixed species and/or poorly stocked stand. The location of a stand also has a bearing on mountain pine beetle success.

When high-hazard stands are intermixed with low-hazard stands, beetle populations may not be as active. Low-hazard stands may have lodgepole pine, but are either not of high enough quality or in large enough quantity to allow beetle populations to remain at high levels. Mountain pine beetle may still cause significant mortality in the lodgepole pine components of low-hazard stands in a landscape, but losses will be lower than in a landscape where high-hazard stands are clustered.

### References

Amman, G.D. 1977. The role of the mountain pine beetle in lodgepole pine ecosystems: impact on succession. In: Mattson, W.J., ed. Arthropods in forest ecosystems. Proceedings in the Life Sciences. New York: Springer-Verlag.

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## Mountain Pine Beetle in Whitebark Pine/ Limber Pine

The high elevation five-needle pines, as a group, provide essential habitat for wildlife, often being the major source of cover in high elevation environments. The range of limber pine partially overlaps with that of whitebark pine. Both species have large, bird-dispersed seeds, and both are highly susceptible to white pine blister rust, an exotic fungus. The two species are so similar in appearance it is only possible to distinguish between them when cones are present. Most recent work on mountain pine beetle in high elevation pines has been centered on whitebark pine; however, much of the information appears to apply to limber pine as well.

### Stand Conditions Conducive To Infestations

Historically the principal natural mortality agent of whitebark pine was the mountain pine beetle (MPB). Perkins (2003) found tree and stand-level characteristics associated with MPB attack in whitebark pine are qualitatively similar to other mountain pine beetle–pine host systems, although the attack thresholds are quantitatively different. Whitebark pine stands with basal areas below 44 ft$^2$/acre and trees with average diameters below 7" were not attacked in the early 20$^{th}$ century epidemic in central Idaho. These factors and other MPB hazard information were used to build the whitebark/limber pine hazard criteria for MPB.

**Hazard Criteria for Mountain Pine Beetle in Whitebark and Limber Pines**

| Criteria | Attribute | Low (.5) | Moderate (2) | High (3) |
|---|---|---|---|---|
| A | QMD whitebark and limber pine (WB+LM) ≥5" DBH | <7" | 7" ≤ QMD < 12" | ≥ 12" |
| B | BA all species (ft$^2$/acre) | <40 ft$^2$/acre | 40 ≤ BA < and 45 ft$^2$/acre | ≥45 ft$^2$/acre |
| C | % of total BA that is whitebark and limber pine ≥5" DBH | <25% | 25% ≤ % BA < 50% | ≥ 50% |

**Directly Calculated Hazard Values and Hazard Rating Multiplicative Index**

| Hazard | Calculated Values | Hazard Rating |
|---|---|---|
| Extremely Low | 0 | 0 |
| Low | <2 | 1, L |
| Moderate | 2-17 | 2, M |
| High | ≥18 | 3, H |

### Interpreting Hazard

Hazard is defined by two factors--the quality and the quantity of susceptible whitebark (WB) and limber pine (LM). The quality of the pine component of a stand as a mountain pine beetle food source is best characterized by stand density and phloem thickness. Since phloem thickness is not generally measured in inventories, DBH and other available stand

characteristics are used as surrogates. The quantity of the food source refers to the species composition and density of the forest. A pure, well stocked pine stand will be more likely to support a large mountain pine beetle population than a mixed species and/or poorly stocked stand.

When high-hazard stands are intermixed with low-hazard stands, beetle populations may not be as active. Low-hazard stands may have WB and LM, but are either not of high enough quality or in large enough quantity to allow beetle populations to remain at high levels. Mountain pine beetle may still cause significant mortality in the WB and LM components of low-hazard stands in a landscape, but losses will be lower than in a landscape where high-hazard stands are clustered.

## References

Arno, S.F. 1986. Whitebark pine cone crops—a diminishing source of wildlife food? Western Journal of Applied Forestry 1: 92–94.

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## Combined Host Pine Beetle

A number of bark beetles, including mountain pine beetle (*Dendroctonus ponderosae*), pine engraver beetles (*Ips* species), and western pine beetle (*Dendroctonus brevicomis*), attack and kill pine (*Pinus*) species. Hazard rating systems have been developed for individual host species; however these systems are not able to accurately assess the hazard of stands containing multiple pine species. It is necessary to group individual pine species components in order to accurately assess hazard.

We developed this hazard rating system by integrating the logic for the individual host species hazard rating systems presented in this document.

**Stand Conditions Conducive To Infestations**

Susceptible mixed pine stands are dense and have a large combined pine species component of trees greater than 7" DBH.

**Hazard Criteria for Mountain Pine Beetle in Lodgepole Pine**

| Criteria | Attribute | Low (.5) | Moderate (2) | High(3) |
|---|---|---|---|---|
| A | QMD whitebark ≥5" DBH or QMD limber ≥ 5"DBH OR QMD western white ≥5" DBH or QMD lodgepole ≥5"DBH OR QMD ponderosa pine ≥5" DBH<br>Start with high- if none of the species meet high, then go to moderate and then to low. Just one of the species needs to meet the criteria to get the rating | <6" | 6" ≤ QMD < 8" | ≥8" |
| B | BA all species ($ft^2$/acre) | <80 $ft^2$/acre | 80 ≤ BA < 120 $ft^2$/acre | 120 ≤ BA |
| C | % of total BA that is whitebark ≥5" DBH + limber ≥ 5"DBH + western white ≥5" DBH +lodgepole ≥5"DBH + ponderosa pine ≥5" DBH + lodgepole pine ≥5" DBH | <25% | 25% ≤ % BA < 50% | ≥50% |

**Directly Calculated Hazard Values and Hazard Rating Multiplicative Index**

| Hazard | Calculated Values | Hazard Rating |
|---|---|---|
| Extremely Low | 0 | 0 |
| Low | <2 | 1, L |
| Moderate | 2-17 | 2, M |
| High | ≥18 | 3, H |

## Interpreting Hazard

Hazard is defined by two factors--the quality and the quantity of susceptible pine. The quality of the pine component of a stand as a mountain pine beetle food source is best characterized by stand density and phloem thickness. Since phloem thickness is not generally measured in inventories, DBH and other available stand characteristics are used as surrogates. The quantity of the food source refers to the species composition and density of the forest. A pure, well stocked pine species stand will be more likely to support a large mountain pine beetle population than a mixed host and non host species and/or poorly stocked stand. The location of a stand also has a bearing on mountain pine beetle success.

When high-hazard stands are intermixed with low-hazard stands, beetle populations may not be as active. Low-hazard stands may have pine components, but are either not of high enough quality or in large enough quantity to allow beetle populations to remain at high levels. Mountain pine beetle may still cause significant mortality in the pine components of low-hazard stands in a landscape, but losses will be lower than in a landscape where high-hazard stands are clustered.

## References

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Taylor, J., Lockman, B., Sturdevant N. 2000. Successional functions of pathogens and insects; ecoregion sections M332a and M333d in northern Idaho and western Montana. Volume 1: Methods. Forest Health Protection Report 00-10. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 39-42 p.

Kegley, S. 2008. Personal Communication. USDA Forest Service, Forest Health Protection Entomologist, Coeur d'Alene Field Office, Coeur d'Alene, ID.

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Perkins, D.L., Roberts, D.W. 2003. Predictive models of whitebark pine mortality from mountain pine beetle. Forest Ecology and Management 174: 495-510.

Perkins, D.L., Swetnam, T.W. 1996. A dendroecological assessment of whitebark pine in the Sawtooth-Salmon River region Idaho. Canadian Journal of Forest Research 26: 2123–2133.

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## Western Spruce Budworm/Douglas-fir Tussock Moth

Western spruce budworm and Douglas-fir tussock moth are defoliating insects which eat the needles of Douglas-fir and true fir trees, though other species may be defoliated during epidemics. When populations of these insects reach epidemic proportions, they can cause a reduction in growth, top kill, tree mortality, and mortality of regenerating trees. Western spruce budworm outbreaks tend to last longer and cause less direct tree mortality because budworms preferentially feed on current year foliage. Douglas-fir tussock moth outbreaks tend to be shorter in duration (2-3 years), but result in more significant mortality losses because tussock moth larvae may completely defoliate a tree.

### Stand Conditions Conducive To Infestations

Because larvae of both species disperse by moving up and out from their egg masses and spinning silken thread to "balloon" on the wind to a new host, they tend to be more destructive in dense (high basal area) stands with a high host (Douglas-fir/true fir) component and multiple canopy layers which intercept ballooning larvae.

**Hazard Criteria for Western Spruce Budworm/Douglas-fir Tussock Moth**

| Criteria | Attribute | Low (.5) | Moderate (2) | High(3) |
|---|---|---|---|---|
| A | BA all species ($ft^2$/acre) | <80 $ft^2$/acre | $80 \leq$ BA < 100 $ft^2$/acre | $\geq$100 $ft^2$/acre |
| B | % of total BA that is: Engelmann spruce, subalpine fir, grand fir, and Douglas-fir $\geq$5" DBH | <50% | 50% $\leq$ % BA < 80% | $\geq$80% |
| C | Trees per acre $\geq$5" DBH | <50 /acre | 50 $\leq$ TPA < 100 /acre | $\geq$100 /acre |

**Directly Calculated Hazard Values and Hazard Rating Multiplicative Index**

| Hazard | Calculated Values | Hazard Rating |
|---|---|---|
| Extremely Low | 0 | 0 |
| Low | <2 | 1, L |
| Moderate | 2-17 | 2, M |
| High | $\geq$18 | 3, H |

### Interpreting Hazard

High-hazard stands are those in which a large amount of Douglas-fir and true fir defoliation is expected once an outbreak of western spruce budworm or Douglas-fir tussock moth occurs. Moderate- and low-hazard stands may experience less defoliation and defoliator-caused growth loss, top kill, or mortality.

When high-hazard stands are intermixed with low-hazard stands, defoliator populations may not be as active. Low-hazard stands may have host species, but are either not of high enough quality or in large enough quantity to allow defoliator populations to remain at high levels. Defoliators may still cause significant mortality in the host components of low-

hazard stands in a landscape, but losses will be lower than in a landscape where high-hazard stands are clustered.

## References


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**APPENDIX 1: Insect_Hazard_Rating. Kcps** Forest Vegetation Simulator keyword files which assign hazard ratings for forest insects to settings in the R1Summary Database. There are 2 .kcp files, A) the Inland Empire, North Idaho & KooKanTL variants B) the Eastern Montana variant.

**A)**

```
********************************************************************************
* IE_Insect_Hazard_rating.kcp  - Forest Health Hazard Rating System   09/22/2011          *
* For IE variant, Uses alpha species codes                                        *
* R1 FHM Staff, derive these hazard ratings based on citations listed in               *
* "R1_Insect_Hazard_Rating.doc", available on the Region1 FRM Website or from Carol
Randall *
*
==================================================================================
=====================*
COMPUTE         0

*ESBtl=Spruce Beetle
ESBtl=(LinInt( &
LinInt(SpMcDBH(5,ES,0,10,99,0,250,0),0,12,12,16,16,99,.5,.5,2,2,3,3)* &
LinInt(SpMcDBH(2,All,0,.1,99,4.5,250,0),0,100,100,150,150,999,.5,.5,2,2,3,3)* &
LinInt((SpMcDBH(2,ES,0,10,99,0,250,0)/Max(SpMcDBH(2,All,0,.1,99,4.5,250,0),1) &
*100),0,50,50,65,65,999,.5,.5,2,2,3,3),0,2,2,18,18,99,1,1,2,2,3,3))* &
Min(Int(SpMcDBH(1,ES,0,0,99,0,250,0)+0.9),1)

*DFBtl=Douglas-fir Beetle
DFBtl=(LinInt( &
LinInt(SpMcDBH(5,DF,0,9,99,0,250,0),0,10,10,14,14,99,.5,.5,2,2,3,3)* &
LinInt(SpMcDBH(2,All,0,.1,99,4.5,250,0),0,100,100,250,250,999,.5,.5,2,2,3,3)* &
LinInt((SpMcDBH(2,DF,0,9,99,0,250,0)/Max(SpMcDBH(2,All,0,.1,99,4.5,250,0),1) &
*100),0,50,50,999,.5,.5,3,3),0,2,2,18,18,99,1,1,2,2,3,3))* &
Min(Int(SpMcDBH(1,DF,0,0,99,0,250,0)+0.9),1)

*PPBtl=Ponderosa Pine (MPB/WPB)
PPBtl=(LinInt( &
LinInt(SpMcDBH(5,PP,0,5,99,0,250,0),0,6,6,10,10,99,.5,.5,2,2,3,3)* &
LinInt(SpMcDBH(2,All,0,.1,99,4.5,250,0),0,80,80,120,120,999,.5,.5,2,2,3,3)* &
LinInt((SpMcDBH(2,PP,0,5,99,0,250,0)/Max(SpMcDBH(2,All,0,.1,99,4.5,250,0),1) &
*100),0,40,40,65,65,999,.5,.5,2,2,3,3),0,2,2,18,18,99,1,1,2,2,3,3))* &
Min(Int(SpMcDBH(1,PP,0,0,99,0,250,0)+0.9),1)

*WPBtl=White Pine (MPB)
WPBtl=(LinInt( &
LinInt(SpMcDBH(5,WP,0,5,99,0,250,0),0,8,8,12,12,99,.5,.5,2,2,3,3)* &
LinInt(SpMcDBH(2,All,0,.1,99,4.5,250,0),0,80,80,120,120,999,.5,.5,2,2,3,3)* &
LinInt((SpMcDBH(2,WP,0,5,99,0,250,0)/Max(SpMcDBH(2,All,0,.1,99,4.5,250,0),1) &
*100),0,25,25,50,50,999,.5,.5,2,2,3,3),0,2,2,18,18,99,1,1,2,2,3,3))* &
```

```
Min(Int(SpMcDBH(1,WP,0,0,99,0,250,0)+0.9),1)

*WBBtl=Whitebark Pine/Limber Pine (MPB)
WBBtl=LinInt(LinInt(13.54*SQRT((SPMCDBH(2,WB,0,5,99)+SPMCDBH(2,LM,0,5,99))/
&
Max((SPMCDBH(1,WB,0,5,99)+SPMCDBH(1,LM,0,5,99)),1)),0,7,7,12,12,99,.5,.5,2,2,3,3)*
&
LinInt(SpMcDBH(2,All,0,.1,99,4.5,250,0),0,40,40,45,45,999,.5,.5,2,2,3,3)* &
LinInt(((SpMcDBH(2,WB,0,5,99,0,250,0)+ SpMcDBH(2,LM,0,5,99,0,250,0))/ &
Max(SpMcDBH(2,All,0,.1,99,4.5,250,0),1)*100),0,25,25,50,50,999,.5,.5,2,2,3,3) &
,0,2,2,18,18,99,1,1,2,2,3,3) * &
Min(Int(SpMcDBH(1,WB,0,0,99,0,250,0)+SpMcDBH(1,LM,0,0,99,0,250,0)+0.9),1)

*LPBtl=Lodgepole Pine 5/2011 (MPB)
LPBtl_New=(LinInt( &
LinInt(SpMcDBH(5,LP,0,5,99,0,250,0),0,7,7,8,8,99,.5,.5,2,2,3,3)* &
LinInt(SpMcDBH(2,All,0,.1,99,4.5,250,0),00,80,80,120,120,250,250,999, &
                              .5,.5, 2,  2,  3,  3, .5, .5)* &
LinInt((SpMcDBH(2,LP,0,5,99,0,250,0)/Max(SpMcDBH(2,All,0,.1,99,4.5,250,0),1) &
*100),0,25,25,50,50,999,.5,.5,2,2,3,3),0,2,2,18,18,99,1,1,2,2,3,3))* &
Min(Int(SpMcDBH(1,LP,0,0,99,0,250,0)+0.9),1)

*CombBtl= Combined 5/2011 (MPB)
BA_SP =
SPMCDBH(2,WB,0,5,99)+SPMCDBH(2,LM,0,5,99)+SPMCDBH(2,WP,0,5,99)+SPMCDBH
(2,LP,0,5,99)+SPMCDBH(2,PP,0,5,99)
BA_ALL = SpMcDBH(2,All,0,.1,99,4.5,250,0)
TPA_SP =
SpMcDBH(1,WB,0,0,99)+SpMcDBH(1,LM,0,0,99)+SpMcDBH(1,WP,0,0,99)+SpMcDBH(1,
LP,0,0,99)+SpMcDBH(1,PP,0,0,99)
QMD_SP =
SPMCDBH(5,WB,0,5,99)+SPMCDBH(5,LM,0,5,99)+SPMCDBH(5,WP,0,5,99)+SPMCDBH
(5,LP,0,5,99)+SPMCDBH(5,PP,0,5,99)

CBtl=LinInt&
(LinInt(13.54*SQRT(BA_SP)/Max(BA_SP,1),0,7,7,12,12,99,.5,.5,2,2,3,3)* &
LinInt(BA_ALL,0,40,40,45,45,999,.5,.5,2,2,3,3)* &
LinInt((BA_SP/Max(BA_ALL,1)*100),0,25,25,50,50,999,.5,.5,2,2,3,3),0,2,2,18,18,99,1,1,2,2,3,
3)* &
Min(Int(TPA_SP +0.9),1)

*BdwTsM=W Spruce Budworm/DF Tussock Moth
BdwTsM=(LinInt( &
LinInt(SpMcDBH(2,All,0,.1,99,4.5,250,0),0,80,80,100,100,999,.5,.5,2,2,3,3)* &
LinInt(((SpMcDBH(2,ES,0,.1,99,4.5,250,0)+SpMcDBH(2,AF,0,.1,99,4.5,250,0)+ &
SpMcDBH(2,GF,0,.1,99,4.5,250,0)+SpMcDBH(2,DF,0,.1,99,4.5,250,0)) &
```

```
/Max(SpMcDBH(2,All,0,.1,99,4.5,250,0),1) &
*100),0,50,50,80,80,999,.5,.5,2,2,3,3)* &
LinInt(SpMcDBH(1,All,0,5,99,0,250,0),0,50,50,100,100,99999,.5,.5,2,2,3,3),&
0,2,2,18,18,99,1,1,2,2,3,3))* &
Min(Int(SpMcDBH(1,ES,0,0,99,0,250,0)+SpMcDBH(1,AF,0,0,99,0,250,0)+ &
SpMcDBH(1,GF,0,0,99,0,250,0)+SpMcDBH(1,DF,0,0,99,0,250,0)+0.9),1)

END
```

B)

```
*****************************************************************************
* EM_Insect_Hazard_rating.kcp  - Forest Health Hazard Rating System   09/22/2011
*
* For EM variant, Uses alpha species codes                                    *
* R1 FHM Staff, derive these hazard ratings based on citations listed in            *
* "R1_Insect_Hazard_Rating.doc", available on the Region1 FRM Website or from Carol
Randall *
*
==============================================================================
======================*
COMPUTE          0

*ESBtl=Spruce Beetle
ESBtl=(LinInt( &
LinInt(SpMcDBH(5,ES,0,10,99,0,250,0),0,12,12,16,16,99,.5,.5,2,2,3,3)* &
LinInt(SpMcDBH(2,All,0,.1,99,4.5,250,0),0,100,100,150,150,999,.5,.5,2,2,3,3)* &
LinInt((SpMcDBH(2,ES,0,10,99,0,250,0)/Max(SpMcDBH(2,All,0,.1,99,4.5,250,0),1) &
*100),0,50,50,65,65,999,.5,.5,2,2,3,3),0,2,2,18,18,99,1,1,2,2,3,3))* &
Min(Int(SpMcDBH(1,ES,0,0,99,0,250,0)+0.9),1)

*DFBtl=Douglas-fir Beetle
DFBtl=(LinInt( &
LinInt(SpMcDBH(5,DF,0,9,99,0,250,0),0,10,10,14,14,99,.5,.5,2,2,3,3)* &
LinInt(SpMcDBH(2,All,0,.1,99,4.5,250,0),0,100,100,250,250,999,.5,.5,2,2,3,3)* &
LinInt((SpMcDBH(2,DF,0,9,99,0,250,0)/Max(SpMcDBH(2,All,0,.1,99,4.5,250,0),1) &
*100),0,50,50,999,.5,.5,3,3),0,2,2,18,18,99,1,1,2,2,3,3))* &
Min(Int(SpMcDBH(1,DF,0,0,99,0,250,0)+0.9),1)

*PPBtl=Ponderosa Pine (MPB/WPB)
PPBtl=(LinInt( &
LinInt(SpMcDBH(5,PP,0,5,99,0,250,0),0,6,6,10,10,99,.5,.5,2,2,3,3)* &
LinInt(SpMcDBH(2,All,0,.1,99,4.5,250,0),0,80,80,120,120,999,.5,.5,2,2,3,3)* &
LinInt((SpMcDBH(2,PP,0,5,99,0,250,0)/Max(SpMcDBH(2,All,0,.1,99,4.5,250,0),1) &
*100),0,40,40,65,65,999,.5,.5,2,2,3,3),0,2,2,18,18,99,1,1,2,2,3,3))* &
Min(Int(SpMcDBH(1,PP,0,0,99,0,250,0)+0.9),1)
```

***WBBtl=Whitebark Pine/Limber Pine (MPB)**
**WBBtl=LinInt(LinInt(13.54*SQRT((SPMCDBH(2,WB,0,5,99)+SPMCDBH(2,LM,0,5,99))/**
**&**
**Max((SPMCDBH(1,WB,0,5,99)+SPMCDBH(1,LM,0,5,99)),1)),0,7,7,12,12,99,.5,.5,2,2,3,3)***
**&**
**LinInt(SpMcDBH(2,All,0,.1,99,4.5,250,0),0,40,40,45,45,999,.5,.5,2,2,3,3)* &**
**LinInt(((SpMcDBH(2,WB,0,5,99,0,250,0)+ SpMcDBH(2,LM,0,5,99,0,250,0))/ &**
**Max(SpMcDBH(2,All,0,.1,99,4.5,250,0),1)*100),0,25,25,50,50,999,.5,.5,2,2,3,3) &**
**,0,2,2,18,18,99,1,1;2,2,3,3) * &**
**Min(Int(SpMcDBH(1,WB,0,0,99,0,250,0)+SpMcDBH(1,LM,0,0,99,0,250,0)+0.9),1)**

***LPBtl=Lodgepole Pine 5/2011 (MPB)**
**LPBtl=(LinInt( &**
**LinInt(SpMcDBH(5,LP,0,5,99,0,250,0),0,7,7,8,8,99,.5,.5,2,2,3,3)* &**
**LinInt(SpMcDBH(2,All,0,.1,99,4.5,250,0),00,80,80,120,120,250,250,999, &**
**.5,.5, 2, 2, 3, 3, .5, .5)* &**
**LinInt((SpMcDBH(2,LP,0,5,99,0,250,0)/Max(SpMcDBH(2,All,0,.1,99,4.5,250,0),1) &**
***100),0,25,25,50,50,999,.5,.5,2,2,3,3),0,2,2,18,18,99,1,1,2,2,3,3))* &**
**Min(Int(SpMcDBH(1,LP,0,0,99,0,250,0)+0.9),1)**

***CombBtl= Combined 5/2011 (MPB)**
**BA_SP =**
**SPMCDBH(2,WB,0,5,99)+SPMCDBH(2,LM,0,5,99)+SPMCDBH(2,LP,0,5,99)+SPMCDBH(**
**2,PP,0,5,99)**
**BA_ALL = SpMcDBH(2,All,0,.1,99,4.5,250,0)**
**TPA_SP =**
**SpMcDBH(1,WB,0,0,99)+SpMcDBH(1,LM,0,0,99)+SpMcDBH(1,LP,0,0,99)+SpMcDBH(1,P**
**P,0,0,99)**
**QMD_SP =**
**SPMCDBH(5,WB,0,5,99)+SPMCDBH(5,LM,0,5,99)+SPMCDBH(5,LP,0,5,99)+SPMCDBH(**
**5,PP,0,5,99)**

**CombBtl=LinInt&**
**(LinInt(13.54*SQRT(BA_SP)/Max(BA_SP,1),0,7,7,12,12,99,.5,.5,2,2,3,3)* &**
**LinInt(BA_ALL,0,40,40,45,45,999,.5,.5,2,2,3,3)* &**
**LinInt((BA_SP/Max(BA_ALL,1)*100),0,25,25,50,50,999,.5,.5,2,2,3,3),0,2,2,18,18,99,1,1,2,2,3,**
**3)* &**
**Min(Int(TPA_SP +0.9),1)**

***BdwTsM=W Spruce Budworm/DF Tussock Moth**
**BdwTsM=(LinInt( &**
**LinInt(SpMcDBH(2,All,0,.1,99,4.5,250,0),0,80,80,100,100,999,.5,.5,2,2,3,3)* &**
**LinInt(((SpMcDBH(2,ES,0,.1,99,4.5,250,0)+SpMcDBH(2,AF,0,.1,99,4.5,250,0)+ &**
**SpMcDBH(2,GF,0,.1,99,4.5,250,0)+SpMcDBH(2,DF,0,.1,99,4.5,250,0)) &**
**/Max(SpMcDBH(2,All,0,.1,99,4.5,250,0),1) &**

```
*100),0,50,50,80,80,999,.5,.5,2,2,3,3)* &
LinInt(SpMcDBH(1,All,0,5,99,0,250,0),0,50,50,100,100,99999,.5,.5,2,2,3,3),&
0,2,2,18,18,99,1,1,2,2,3,3))* &
Min(Int(SpMcDBH(1,ES,0,0,99,0,250,0)+SpMcDBH(1,AF,0,0,99,0,250,0)+ &
SpMcDBH(1,GF,0,0,99,0,250,0)+SpMcDBH(1,DF,0,0,99,0,250,0)+0.9),1)

END
```